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ENCE 331: Compressibility of soil

Previously in Soil Mechanics

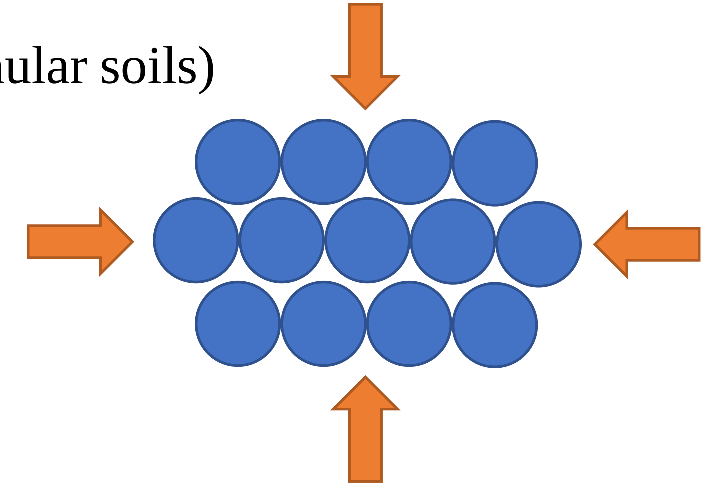
- Origin of soil
- Weight-Volume relationships
- Plasticity of soil
- Classification of soil
- Permeability and Seepage
- In-situ stresses
- Stress in soil mass
- Compressibility
- Shear Strength

Why shear strength ??

- Soil is made from individual particles (sediments)
- The strength of the soil is contributed to the interaction between these particles
- This interaction takes two forms
  - Cohesion (adhesion between the particles)

    Depends on type of soil (Clay soils)
  - Friction

    Depends on roughness of particles, particle size, and normal stress (Granular soils)
- The forces that break this interaction are shear forces



Mohr-Coulomb Failure criteria

Table 12.1 Typical Values of Drained Angle of Friction for Sands and Silts

Soil type	ϕ' (deg)
Sand: Rounded grains	
Loose	27–30
Medium	30–35
Dense	35–38
Sand: Angular grains	
Loose	30–35
Medium	35–40
Dense	40–45
Gravel with some sand	34–48
Silts	26–35

- The components of shear stress are:
  - Cohesion
  - Friction
- Mohr (1900) presented a theory for rupture in materials that contended that a material fails because of a critical combination of normal stress and shearing stress

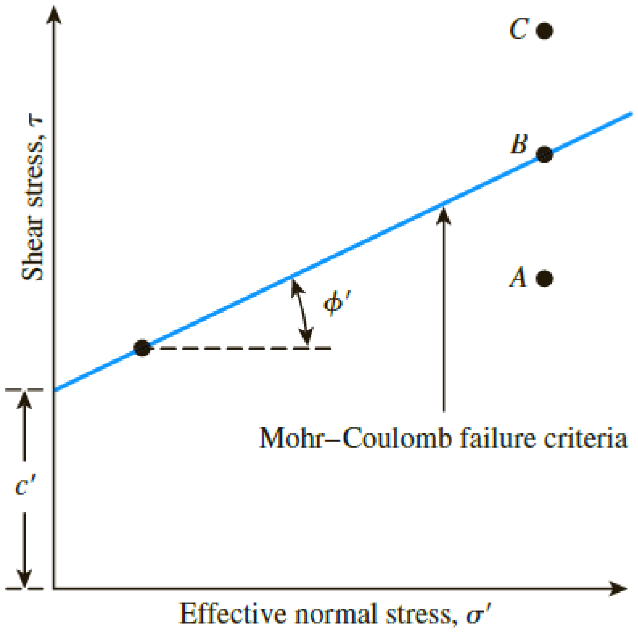
$$\tau_f = c' + \sigma' \tan \phi' \quad \text{OR} \quad \tau_f = c + \sigma \tan \phi$$

where c = cohesion

ϕ = angle of internal friction

σ = normal stress on the failure plane

τ_f = shear strength

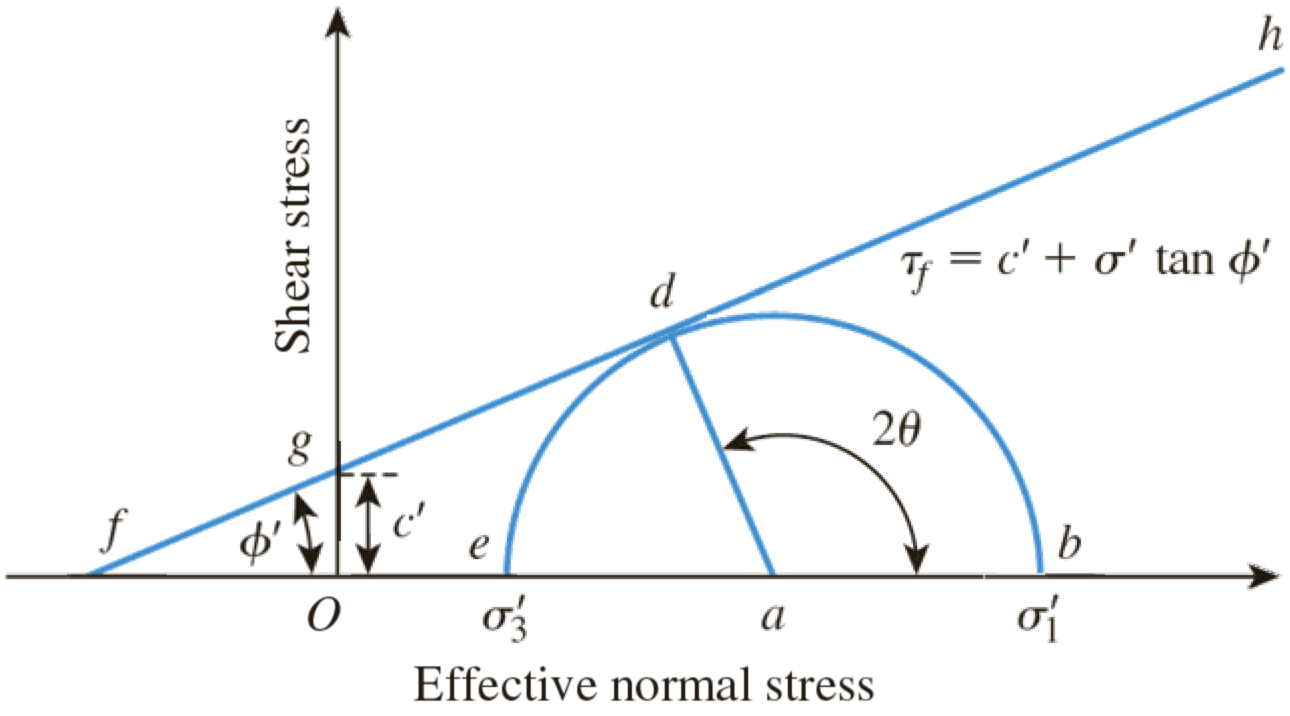


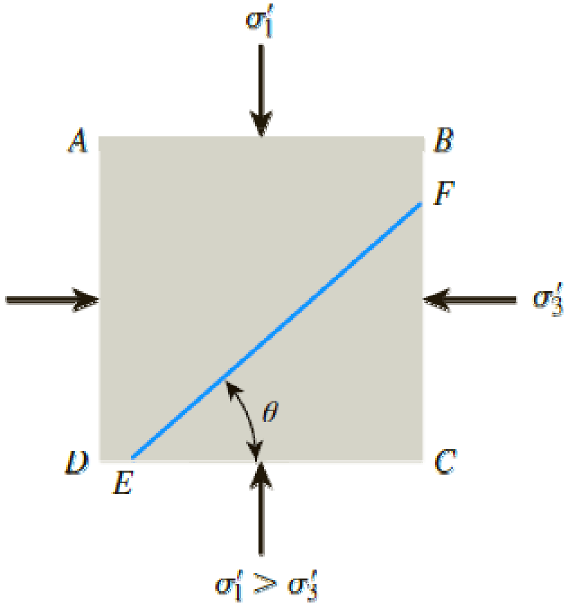
Mohr's Circle and stress transformation

- Since we usually deal with vertical stress (Comp), we need to find the most critical surface (failure plane)
- For this we use, ……………??

$$\theta = 45 + \frac{\phi'}{2}$$

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$$





LAB tests to determine shear strength of soil

- There are many test that can be conducted either in the lab or in the field to determine the soil strength parameters (C,ϕ)
  - LAB tests
    - Direct Shear Test.
    - Triaxial Compression Test.
    - Unconfined Compression (UCC) Test.
  - Field tests
    - Vane Shear Test.
    - Bore Hole Shear Test.
- Lab tests are more accurate, but require more time and samples will be disturbed to some degree
- Field tests are usually faster, no need to take samples (Undisturbed soil), but it is less accurate.

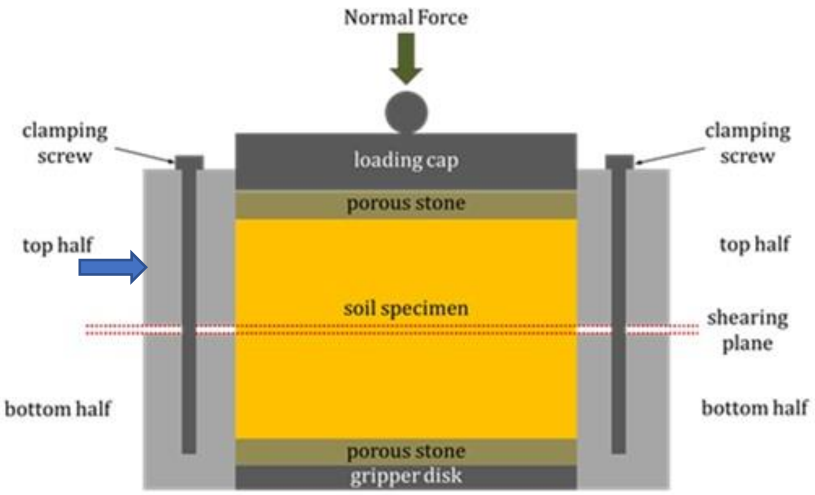
Direct shear test

- The test apparatus is shown
- First the Normal force is applied incrementally so that the sample can consolidate
- The normal stress is

$$\sigma = \text{Normal stress} = \frac{\text{Normal force}}{\text{Cross-sectional area of the specimen}}$$

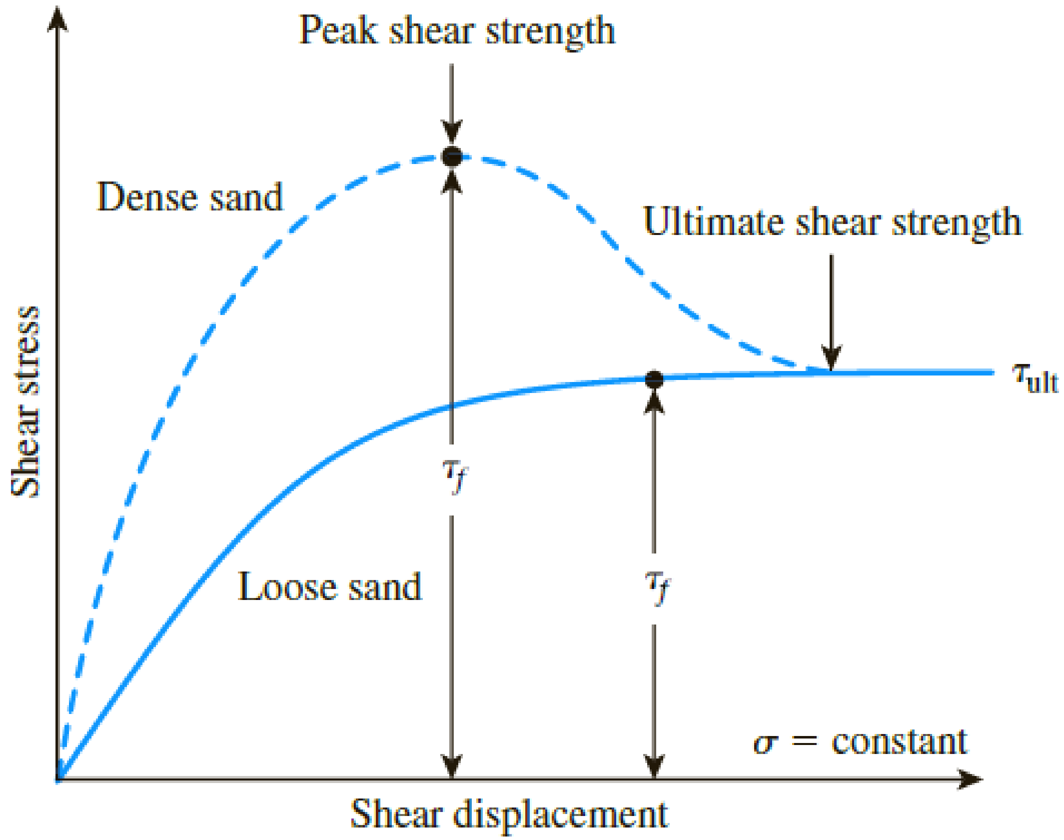
- Then a Horizontal force is applied to the Top half and increased incrementally to failure, and the lateral displacement is measured
- The shea

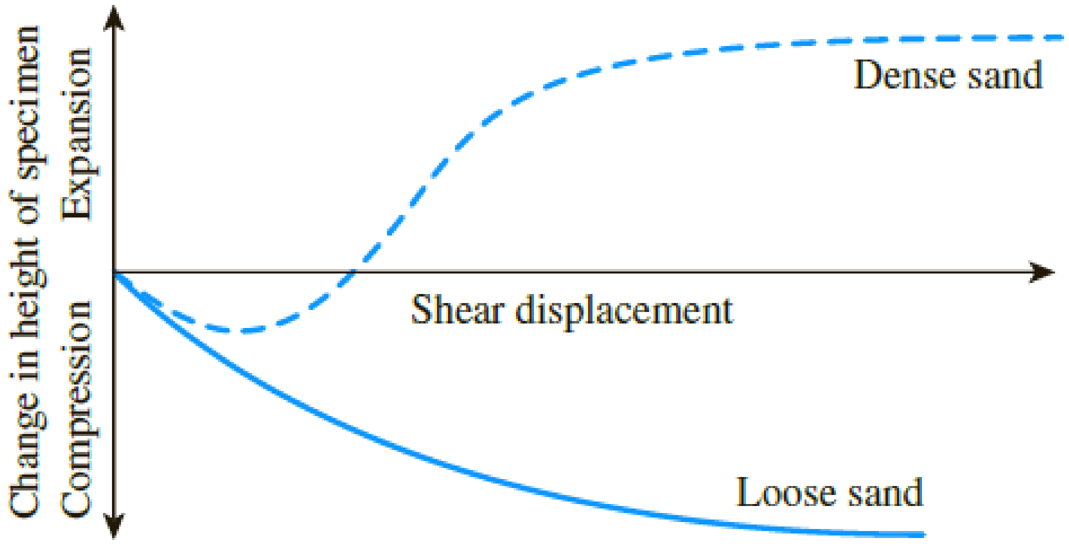
$$\tau = \text{Shear stress} = \frac{\text{Resisting shear force}}{\text{Cross-sectional area of the specimen}}$$



51 mm × 51 mm or 102 mm × 102 mm 25 mm (1 in.) high.

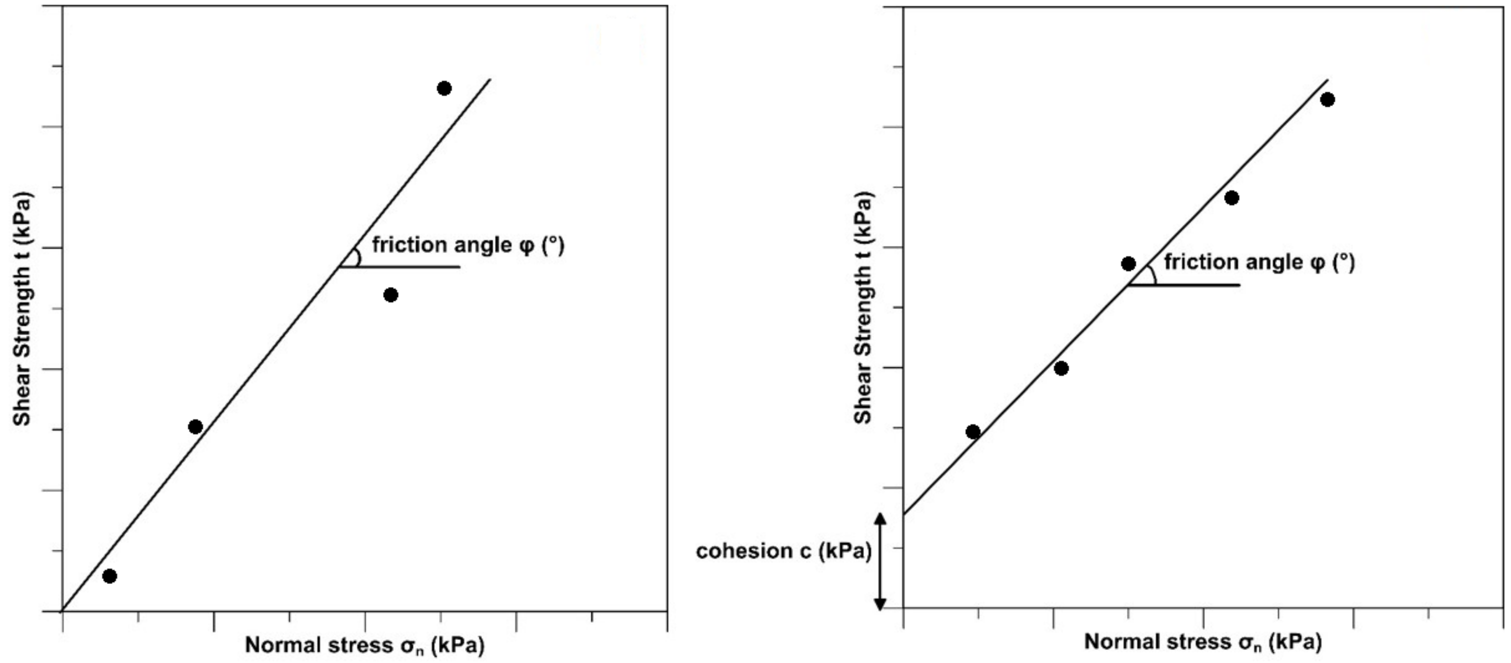
Direct shear test





Direct shear test

- The test is repeated for different specimens of the same soil for different Normal stresses
- Each time the Normal stress and the shear stress at failure are recorded



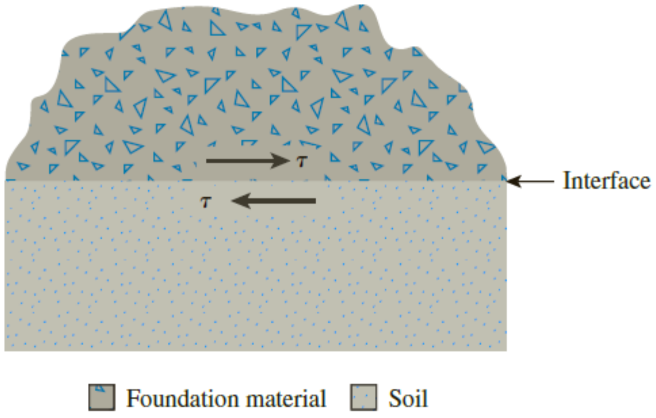
Direct shear test

- General Comments
  - The soil is not allowed to fail along the weakest plane but is forced to fail along the plane of split of the shear box
  - The shear stress distribution over the shear surface of the specimen is not uniform
  - Progressive failure

  - Despite its shortcomings The direct shear test is simple to perform
  - The test can be utilized to determine the interface properties

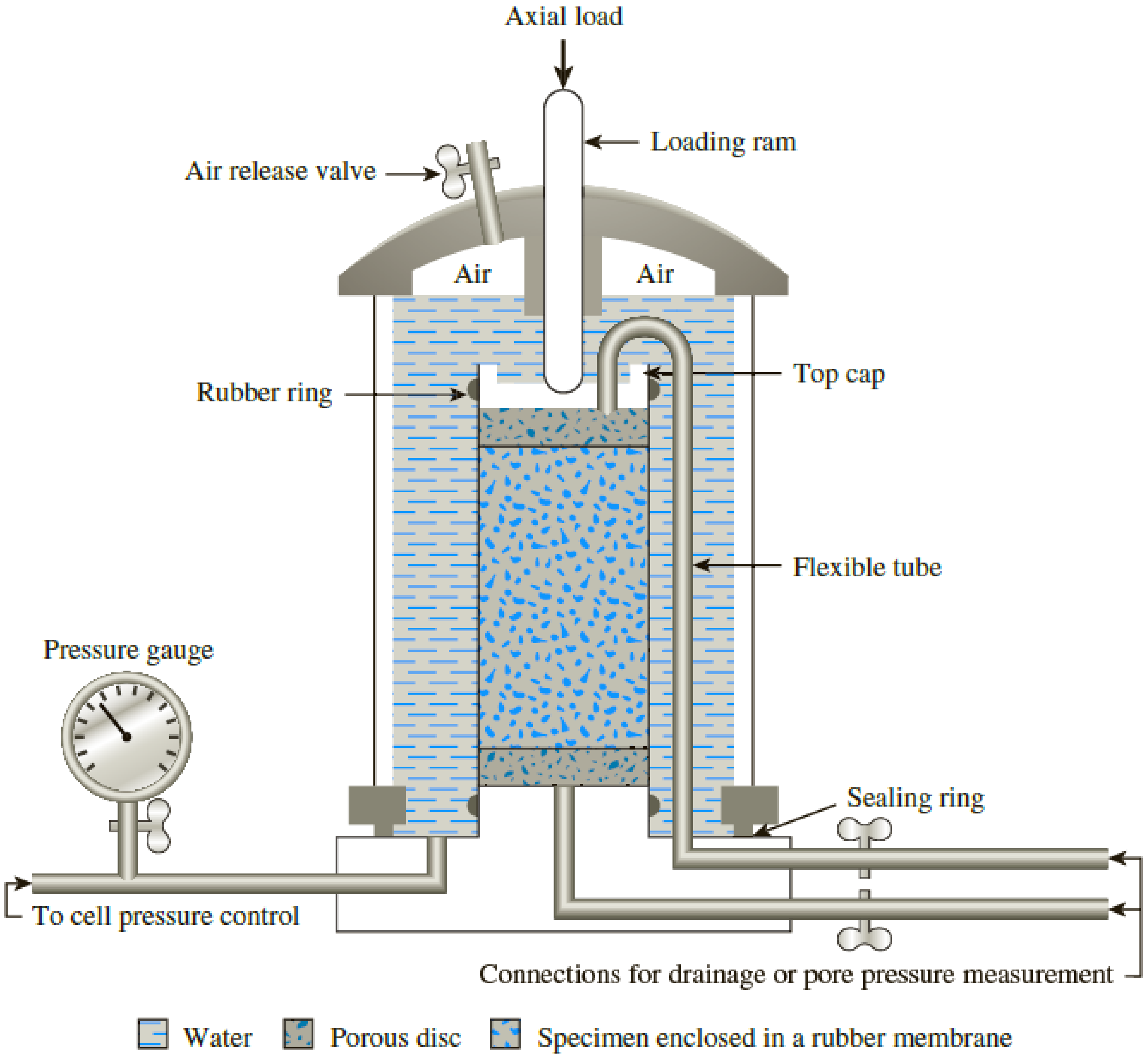
$$\tau_f = c'_a + \sigma' \tan \delta'$$

where c'_a = adhesion
δ' = effective angle of friction between the soil and the foundation meterial



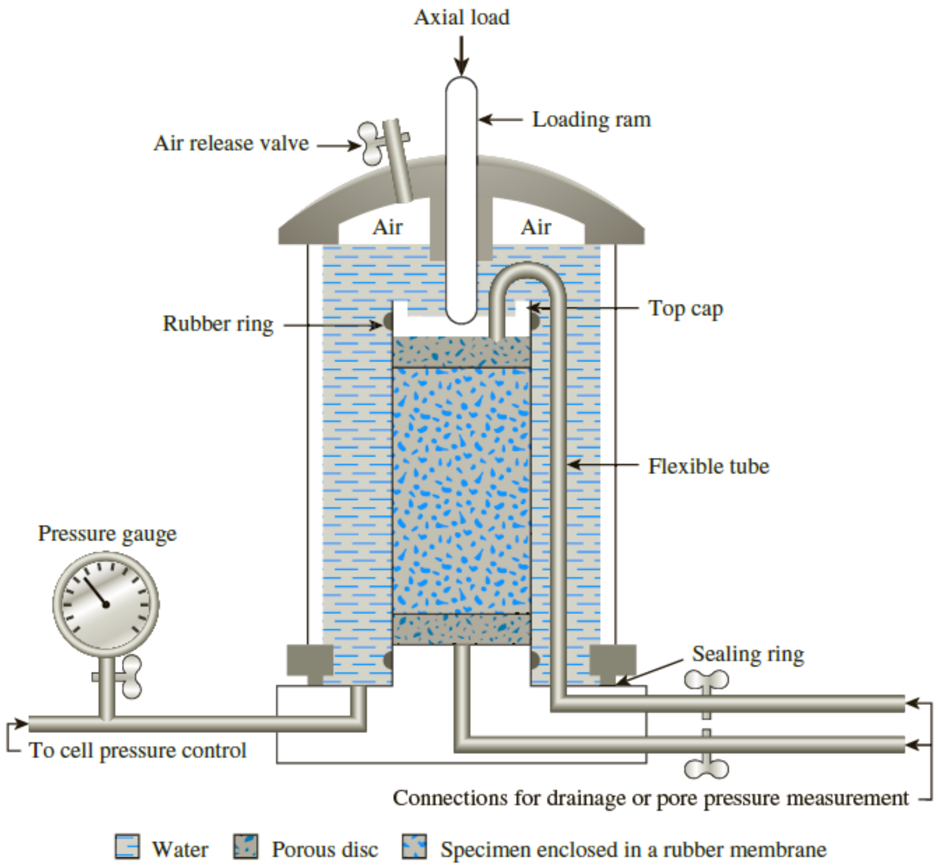
Tri-Axial test

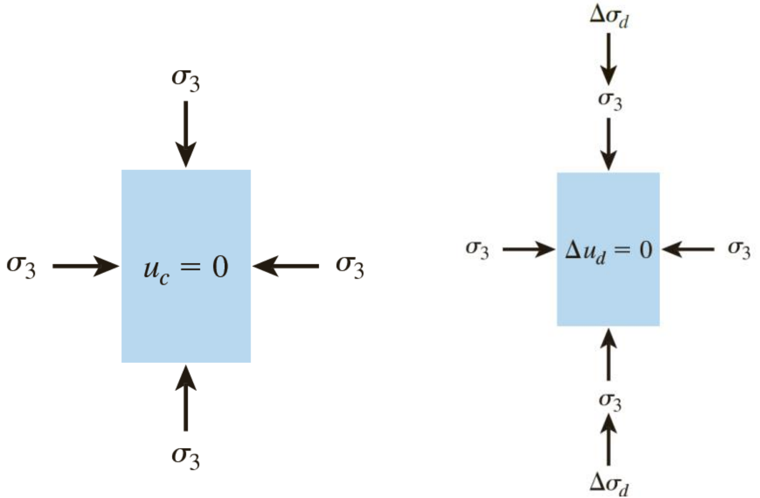
- The triaxial shear test is one of the most reliable methods available for determining shear strength parameters
- Soil specimen about 36 mm (1.4 in.) in diameter and 76 mm (3 in.) long
- The specimen is subjected to a confining pressure by compression of the fluid in the chamber
- The axial load applied by the loading ram and the corresponding axial deformation is measured by a ring or load cell attached to the ram



Tri-Axial test

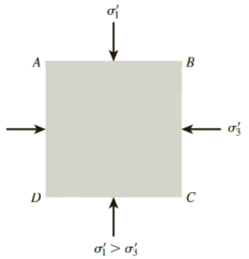
- The test is performed in two stages
  - Appling the confining pressure (σ_3)
    - If the drainage is open, then the excess pore water pressure is …………
    - Depending on the drainage, the test can be Consolidated or Unconsolidated test
  - Appling the deviatoric pressure ($\Delta\sigma_d$)
    - If the drainage is open, then the excess pore water pressure is …………
    - Depending on the drainage, the test can be Drained or Undrained test
- Depending on the drainage conditions at each stage the following three standard types of triaxial tests generally are conducted:
  - Consolidated-drained test or drained test (CD test)
  - Consolidated-undrained test (CU test)
  - Unconsolidated-undrained test or undrained test (UU test)



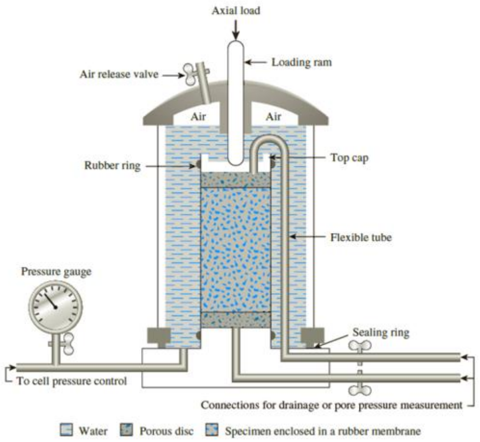


Tri-Axial test

- Consolidated-drained test or drained test (CD test)
  - the saturated specimen first is subjected to an all-around confining pressure, σ_3, by compression of the chamber fluid
  - The sample is allowed to consolidate until the pore pressure is completely dissipated
  - Then the deviatoric axial stress is applied incrementally to failure
  - The stress state for any element shown is called ……………
  - Total and effective confining stress = σ_3 = σ_3'
  - Total and effective axial stress at failure σ_1 = σ_1'= $\Delta\sigma_d + \sigma_3$

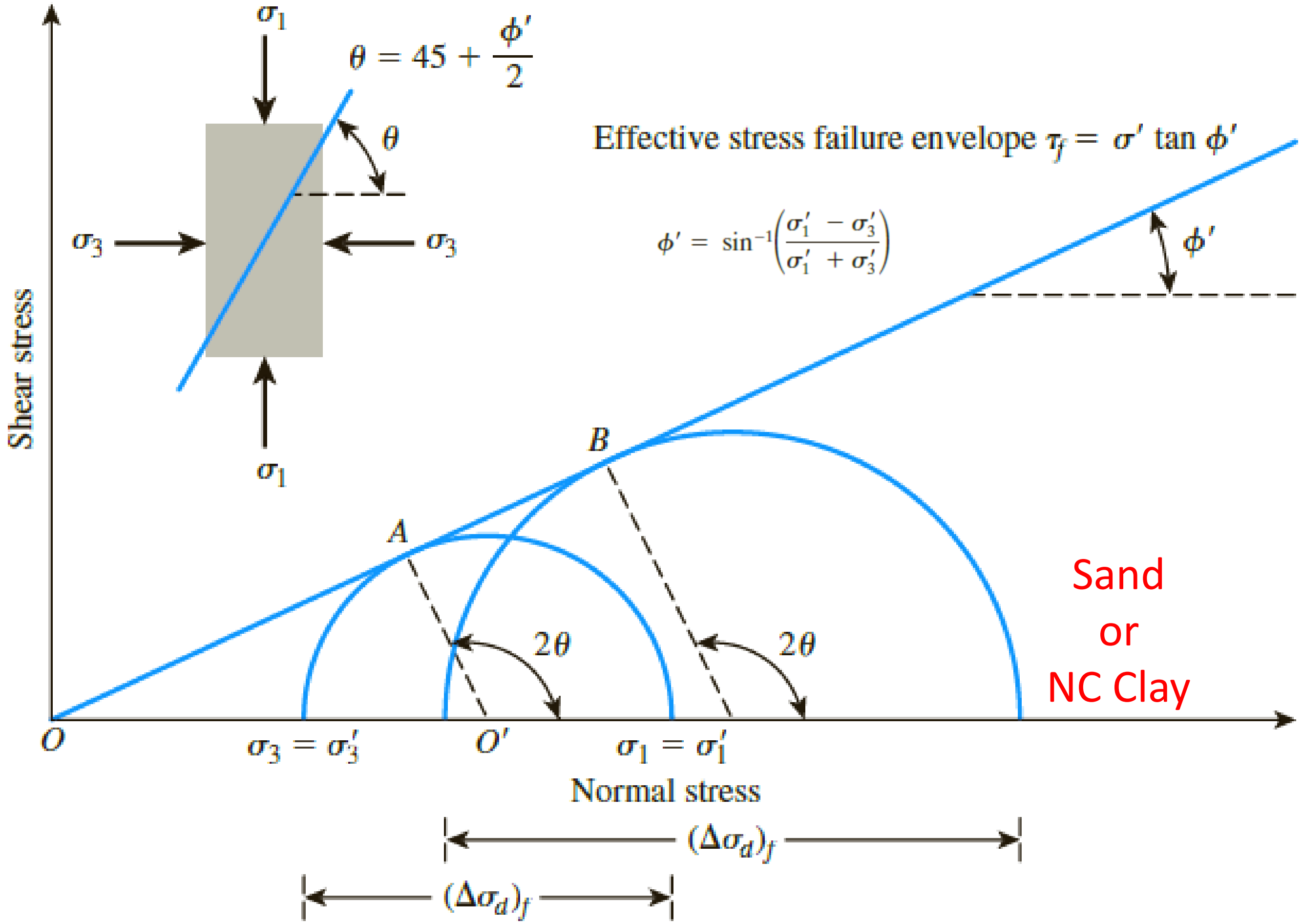


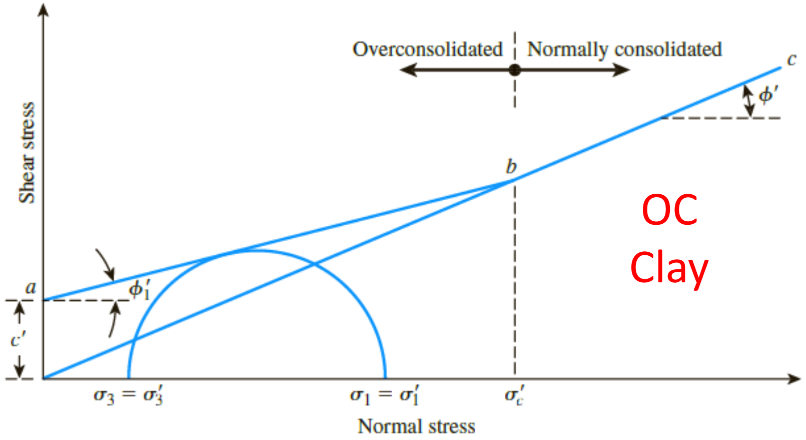
  - The test is repeated at least two times at different confining pressures
  - The confining pressure and the deviatoric stress at failure are recorded



Tri-Axial test

- Consolidated-drained test or drained test (CD test)



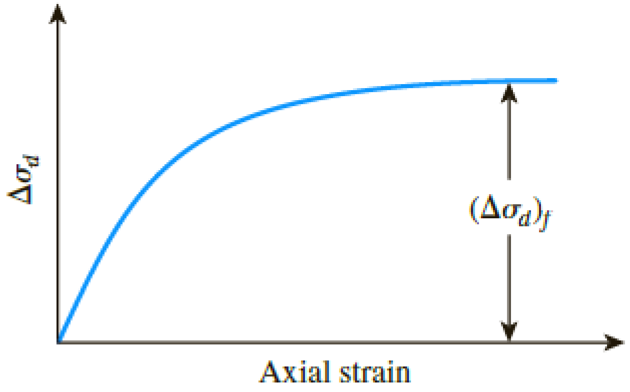


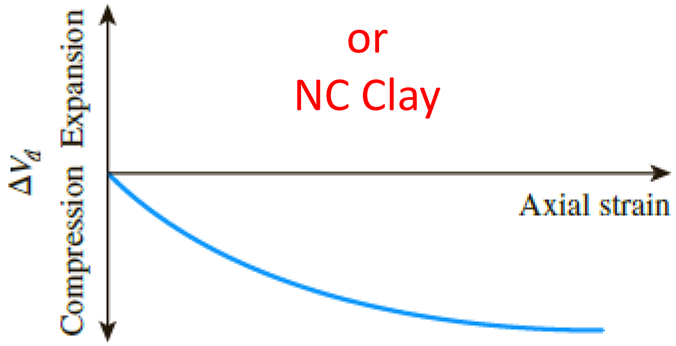
$$\phi_1' = 2\left\{ \tan^{-1}\left[\frac{\sigma'_{1(1)} - \sigma'_{1(2)}}{\sigma'_{3(1)} - \sigma'_{3(2)}}\right]^{0.5} - 45°\right\}$$

$$c' = \frac{\sigma'_{1(1)} - \sigma'_{3(1)} \tan^2\left(45 + \frac{\phi_1'}{2}\right)}{2 \tan\left(45 + \frac{\phi_1'}{2}\right)}$$

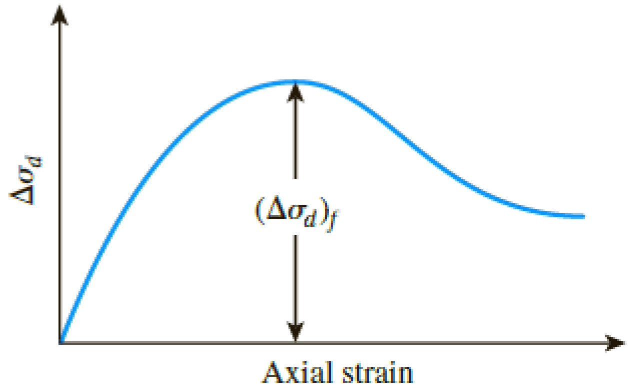
Tri-Axial test

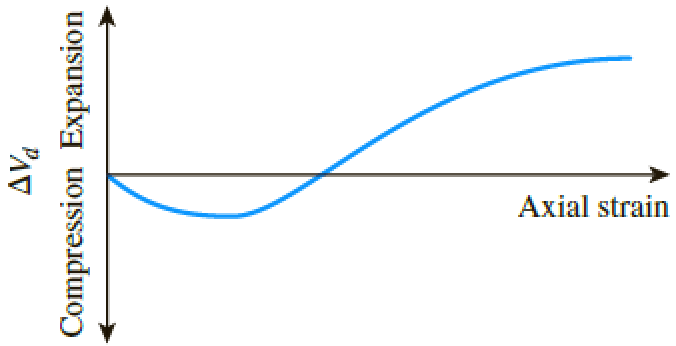
- Consolidated-drained test or drained test (CD test)





Loose Sand
or
NC Clay





Dense Sand
or
OC Clay

Tri-Axial test

- Consolidated-drained test or drained test (CD test)

  Example:

  The results of two drained triaxial tests on a saturated clay follow:

  Specimen I:

  σ_3 =70 kN/m2

  $\Delta\sigma_{d,f}$ =130 kN/m2

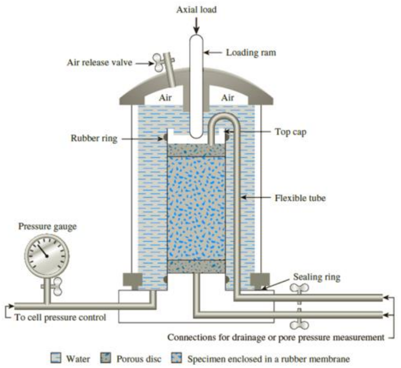
  Specimen II:

  σ_3 = 160 kN/m2

  $\Delta\sigma_{d,f}$ = 223.5 kN/m2

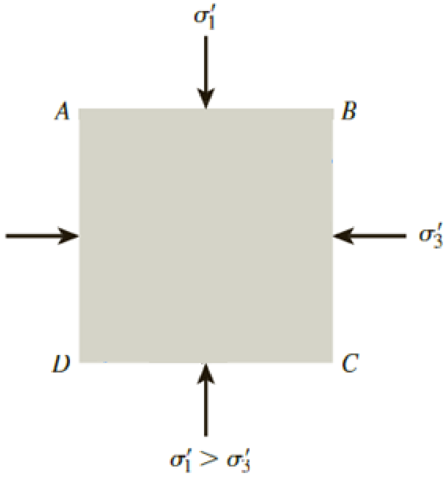
  Determine the shear strength parameters.

Tri-Axial test



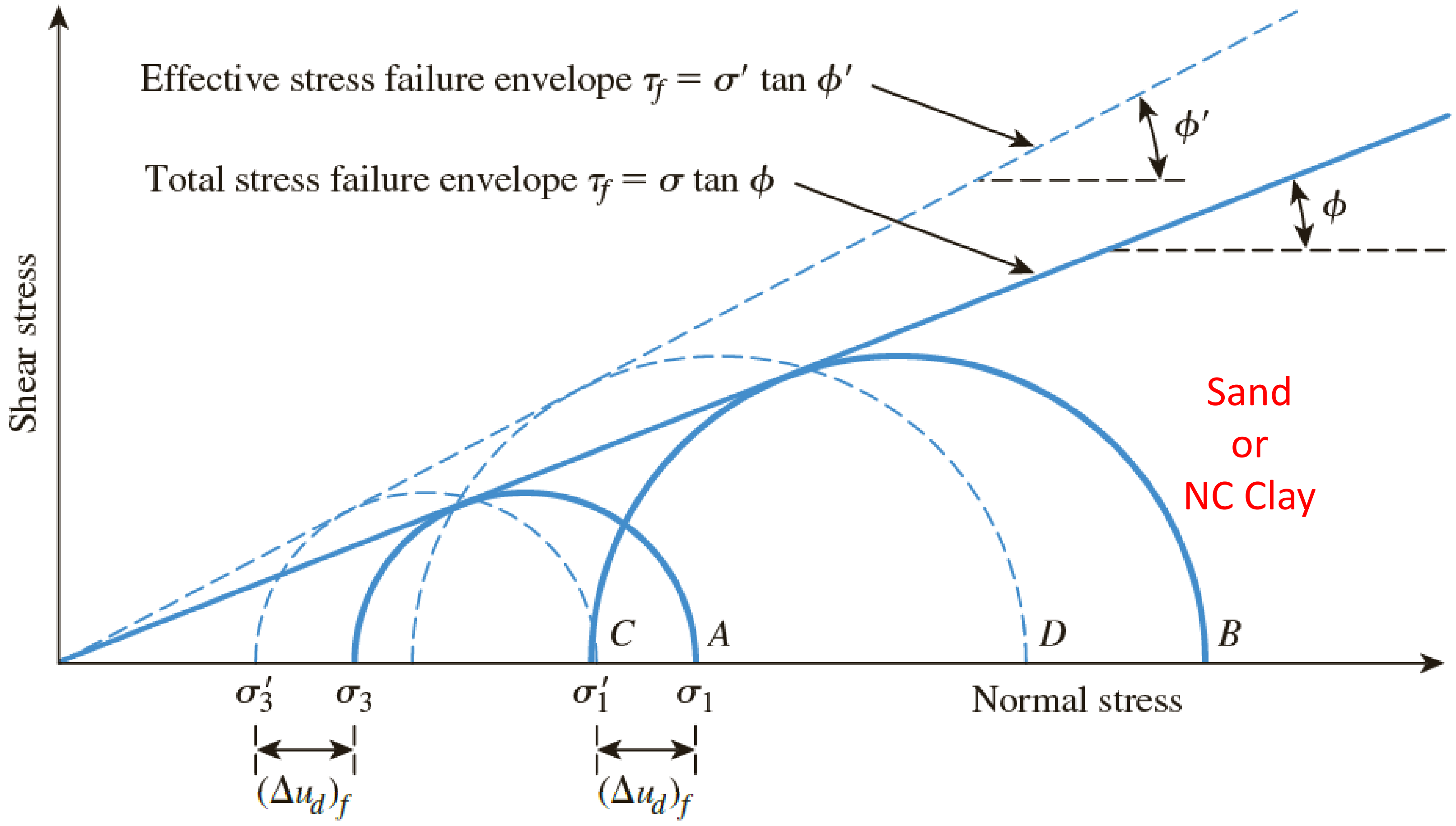
- Consolidated-Undrained test (CU test)
  - This test is the most common type of triaxial test
  - We can measure the effective soil strength parameters (C', ϕ') and the total stress parameters (C, ϕ)
  - Consolidated-drained tests on clay soils take considerable time.
  - Saturated soil specimen is first consolidated by an all-around chamber fluid pressure σ_3
  - Then the drainage is closed and the deviatoric axial stress is applied to failure $\Delta\sigma_{d,f}$
  - This will result in an increase in the pore water pressure $\Delta u_{d,f}$

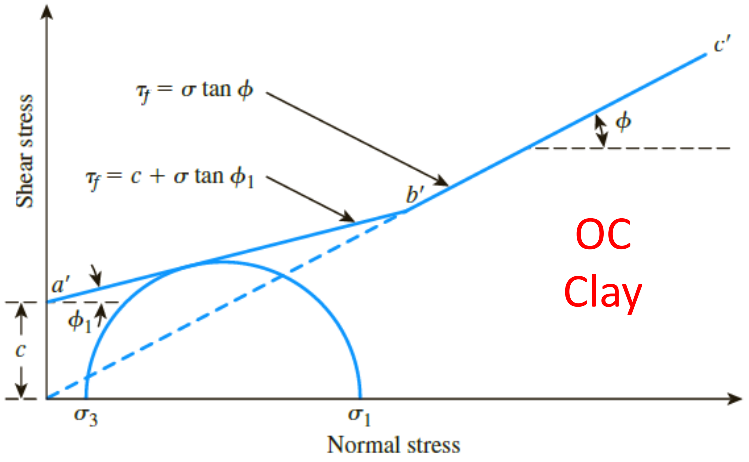
  - Major principal stress at failure (total): $\sigma_1 = \sigma_3 + \Delta\sigma_{d.f}$
  - Major principal stress at failure (effective): $\sigma_1' = \sigma_1 - \Delta u_{d.f}$
  - Minor principal stress at failure (total): σ_3
  - Minor principal stress at failure (effective): $\sigma_3' = \sigma_3 - \Delta u_{d.f}$



Tri-Axial test

$$\phi = \sin^{-1}\left(\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}\right) \qquad \phi' = \sin^{-1}\left[\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 - 2(\Delta u_d)_f}\right]$$





Tri-Axial test

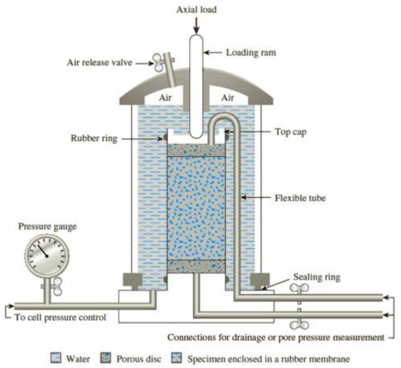
- Consolidated-Undrained test or drained test (CU test)
  - Example:

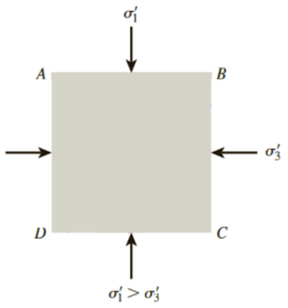
    A specimen of saturated sand was consolidated under an all-around pressure of 105 kN/m2. The axial stress was then increased, and drainage was prevented.

    The specimen failed when the axial deviator stress reached 70 kN/m2. The pore water pressure at failure was 50 kN/m2. Determine

    a. Consolidated-undrained angle of shearing resistance, ϕ
    b. Drained friction angle, ϕ'

Tri-Axial test



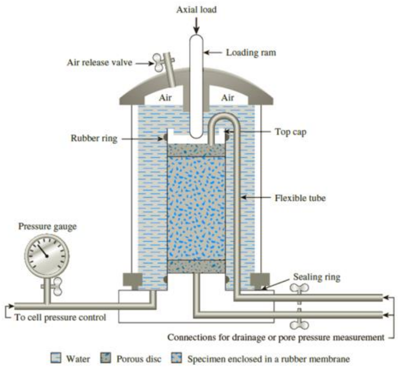


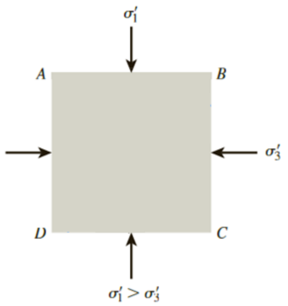
- Unconsolidated-Undrained Triaxial Test (UU)
  - This test usually is conducted on clay specimens
  - We can measure the effective soil strength parameters (C', ϕ') and the total stress parameters (C, ϕ)
  - Because drainage is not allowed at any stage, the test can be performed quickly
  - Saturated soil specimen is subjected to an all-around chamber fluid pressure σ_3 with drainage closed
  - The pore water pressure in the soil specimen will increase by u_c
  - Then the deviatoric axial stress is applied to failure $\Delta\sigma_{d,f}$
  - This will result in an increase in the pore water pressure $\Delta u_{d,f}$
  - The total pore water pressure u in the specimen at any stage of deviator stress application $u = u_c + \Delta u_d$

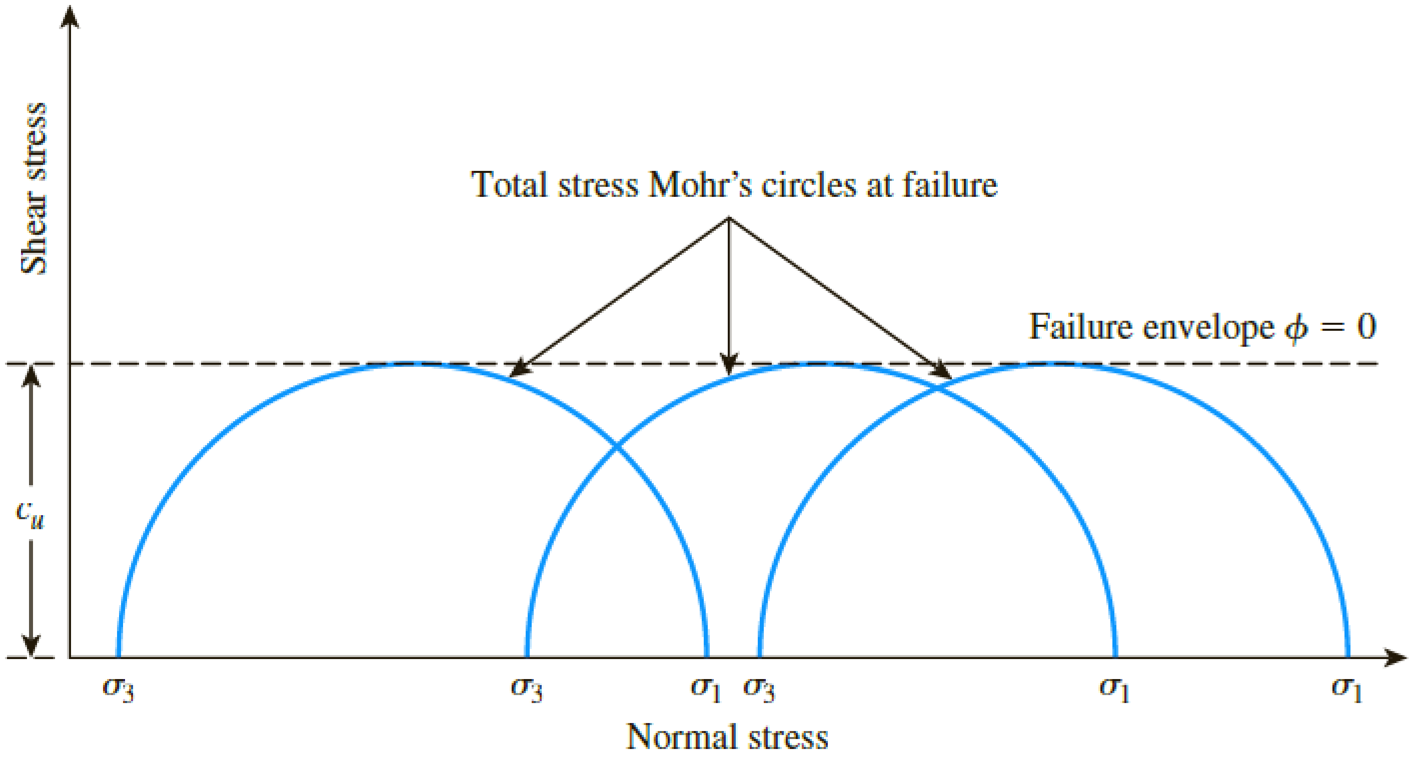
  - The added axial stress at failure $\Delta\sigma_{d,f}$ is practically the same regardless of the chamber confining pressure

Tri-Axial test

- Unconsolidated-Undrained Triaxial Test (UU)







Tri-Axial test

- Unconfined Compression Test on Saturated Clay
  - This test is a special type of unconsolidated-undrained test that is commonly used for clay specimens
  - Since the undrained shear strength of clay doesn't depend on the confining pressure σ_3
  - The test is performed without any confining pressure $\sigma_3 = 0$
  - Theoretically, for similar saturated clay specimens, the unconfined compression tests and the unconsolidated-undrained triaxial tests should yield the same values of c_u
  - In practice, however, unconfined compression tests on saturated clays yield slightly lower values